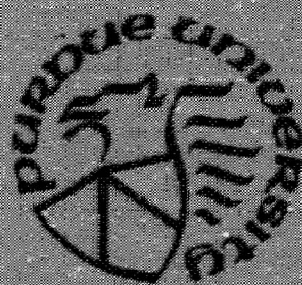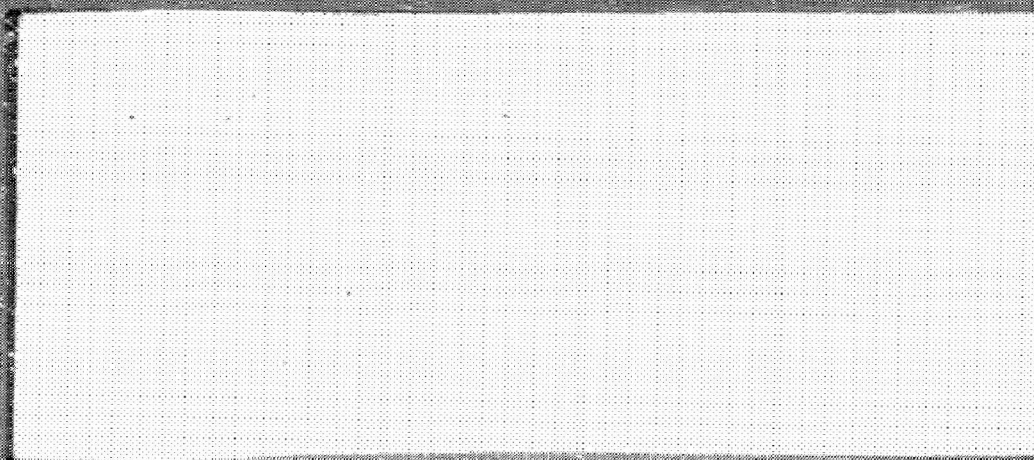# RAY W. HERRICK LABORATORIES

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A STUDY OF METHODS TO PREDICT AND MEASURE
THE TRANSMISSION OF SOUND THROUGH THE WALLS OF LIGHT AIRCRAFT

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A STUDY OF METHODS OF PREDICTION AND
MEASUREMENT OF THE TRANSMISSION OF
SOUND THROUGH THE WALLS OF LIGHT AIRCRAFT

Sponsored by:

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1. INTRODUCTION

This report presents results obtained during the six month period from May to October, 1981 in the studies of sound transmission through light aircraft walls. This report discusses work which has been conducted since the first Annual Report which was submitted in August 1981 [1].

The SEA theory was used to develop a theoretical model to predict the transmission loss through an aircraft window. This work mainly consisted of the writing of two computer programs. One program predicts the sound transmission through a plexiglass window (the case of a single partition). The other program applies to the case of a plexiglass window with a window shade added (the case of a double partition with an air gap).

In the experimental studies, the sound transmission through a structure was measured using several different methods in order that the accuracy and complexity of all the methods could be compared. Also, the measurements were conducted on the simple model of a fuselage (a cylindrical shell), and on a real aircraft fuselage as well.

2. THEORETICAL STUDIES

A theoretical model to predict the sound transmission through an aircraft window has been developed by using SEA

theory. The main idea of this model is obtained from the theory described in two Crocker and Price papers [2,3]. Two computer programs have been written to calculate the transmission loss of single and double panels based on the SEA theory. The single panel case was applied to the plexiglass window on the fuselage. Figure 1 shows that very good agreement is achieved between experimental data and theory. The computer program, which predicts the transmission loss through double panels, is used for the case when a window shade is added to the plexiglass window of the aircraft under investigation. The theoretical prediction and the experimental results are shown in Figure 2. It should be noted that the good agreement obtained in Figures 1 and 2 indicates that the plexiglass window is acting like a flat panel though it is slightly curved.

3. EXPERIMENTAL RESULTS

The following three aspects of the sound transmission through a structure have been studied experimentally:

1. Sound transmission through a cylindrical shell in the inward and outward directions.

2. Sound transmission through a cylindrical shell measured by the conventional transmission suite method.

3. Sound transmission through an aircraft fuselage.

3.1 Sound Transmission Through a Cylindrical Shell

Sound transmission through a cylindrical shell in the outward direction was measured and presented in the previous report [1]. It was noticed that in the low frequency region, the interior volume of the cylinder can hardly be approximated by an acoustic reverberant field. In order to improve the measurements, a large amount of wedge-shaped fiberglass was placed inside the cylinder to make the interior volume approximate an acoustical free-field. Two microphones were installed inside the cylinder to measure the sound intensity transmitted into the cylinder. The cylinder was suspended in the reverberation room and a diffuse sound field was created in the room. The results from this set-up were compared to those from the previous set-up where the sound source was installed in the cylinder which was situated in the anechoic room. In the frequency range above 1500 Hz, Figure 3 shows that very good agreement was obtained between the cylinder transmission losses for the sound field approaching the cylinder in the two directions. It should be noted that this result was hoped for, since in each case a diffuse randomly incident sound field approaches the cylinder and is transmitted to an anechoic receiving space. In the lower frequency region, since it is easier to create a low frequency reverberation field in a reverberation room than in the cylinder interior, it is believed that the results obtained from the present set-up are better than those from the previous set-up.

3.2 Transmission Suite Method

An alternative method to measure the transmission loss of a structure, other than the two microphone intensity method, is the transmission suite method. It is a widely used method and requires two reverberant fields to be created. In our experiment, the cylinder was placed in a diffuse reverberant field in the reverberation room. In this transmission suite approach, a series of measurements must be made including: the spatially-averaged sound pressure levels inside and outside the cylinder, and the reverberation time of the interior volume of the cylinder. The sound transmission loss (TL) is then calculated from the noise reduction (NR) which is defined as the difference in sound pressure levels between the interior and exterior sound fields of the cylinder. The transmission loss measured from this method compared well with that obtained from the two-microphone intensity method as is shown in Figure 4. The agreement between the two methods gives a check and further confidence in the two-microphone intensity method, which is considered to be a much simpler measurement procedure.

3.3 Sound Transmission Through Fuselage

The sound transmission through a Piper Cherokee aircraft fuselage (Model PA 28-140) was measured. The fuselage was suspended in the reverberation room during the measurements, and the transmission losses through different sections of the fuselage were determined. As shown in Figure 5, the transmission

loss of the panel (with the interior trim) is greater than that of the plexiglass window in the higher part of the frequency region shown. Measurements were also made on the bare aluminum panel when the trim and fiberglass spacer were removed. In this case, the transmission loss was about the same for the bare panel as for the plexiglass window. A brief study was made of the transmission loss of the door slit. It is shown in Figure 6 that high frequency noise seems mainly to pass through the door slit rather than through the door panel.

4. REFERENCES

[1] Forssen, B., Wang, Y.S., Raju, P.K., and Crocker, M.J., "A Study of Methods of Prediction and Measurement of the Transmission of Sound Through the Walls of Light Aircraft," Herrick Lab Report HL 81-19, Purdue University, August 1981.

[2] Crocker, M.J., and Price, A. J., "Sound Transmission Using Statistical Energy Analysis," J. of Sound Vibration, Vol. 9, No. 3, pp. 469-486, 1969.

[3] Price, A.J., and Crocker, M.J., "Sound Transmission Through Double Panels Using Statistical Energy Analysis," J. of the Acoustical Society of America, Vol. 47, No. 3, 1970, pp. 683-693.
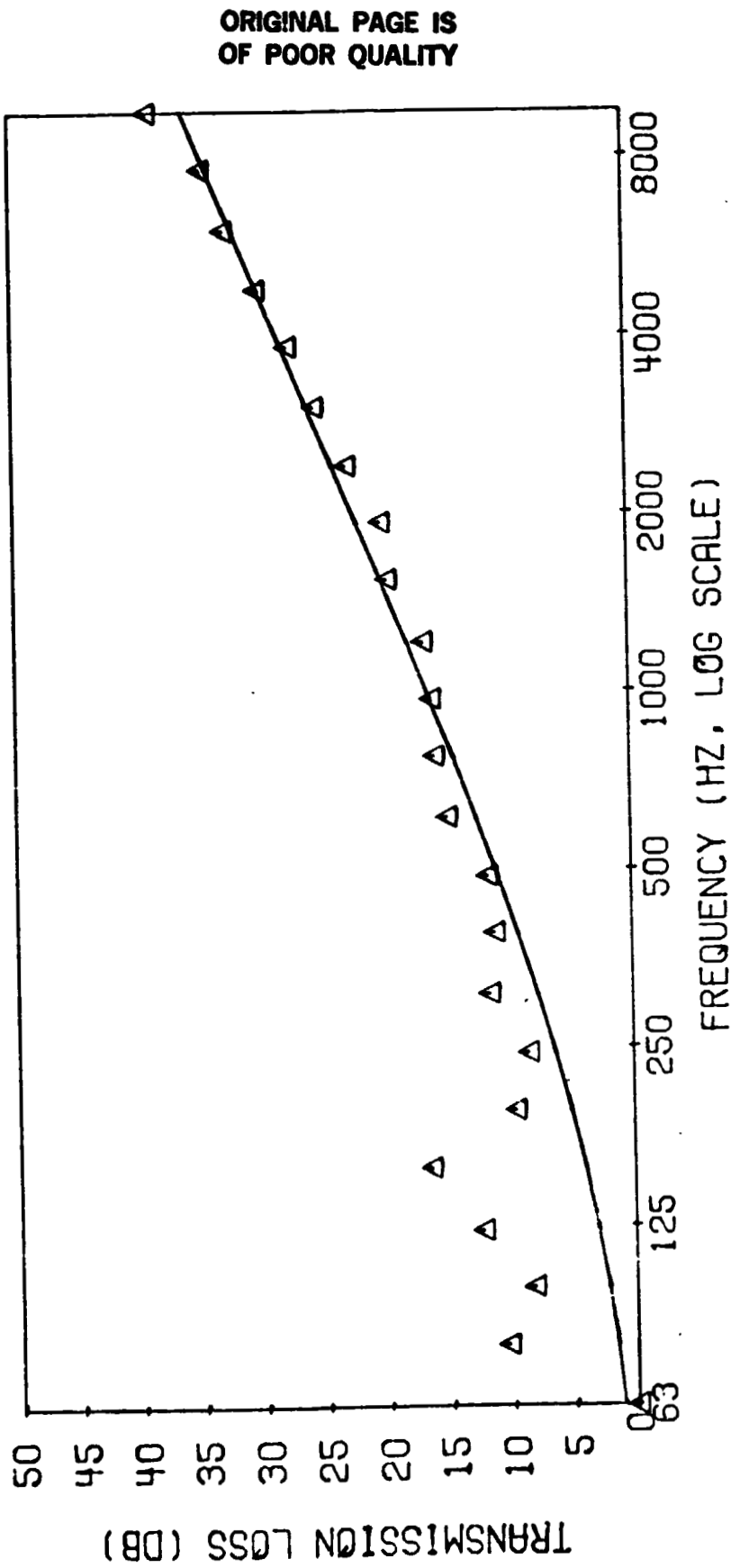
Fig. 1. Comparison Between Theoretical Prediction ----- of Transmission Loss
and the Measured Results (at 1/3 Octave Center Frequencies, Marked as △)
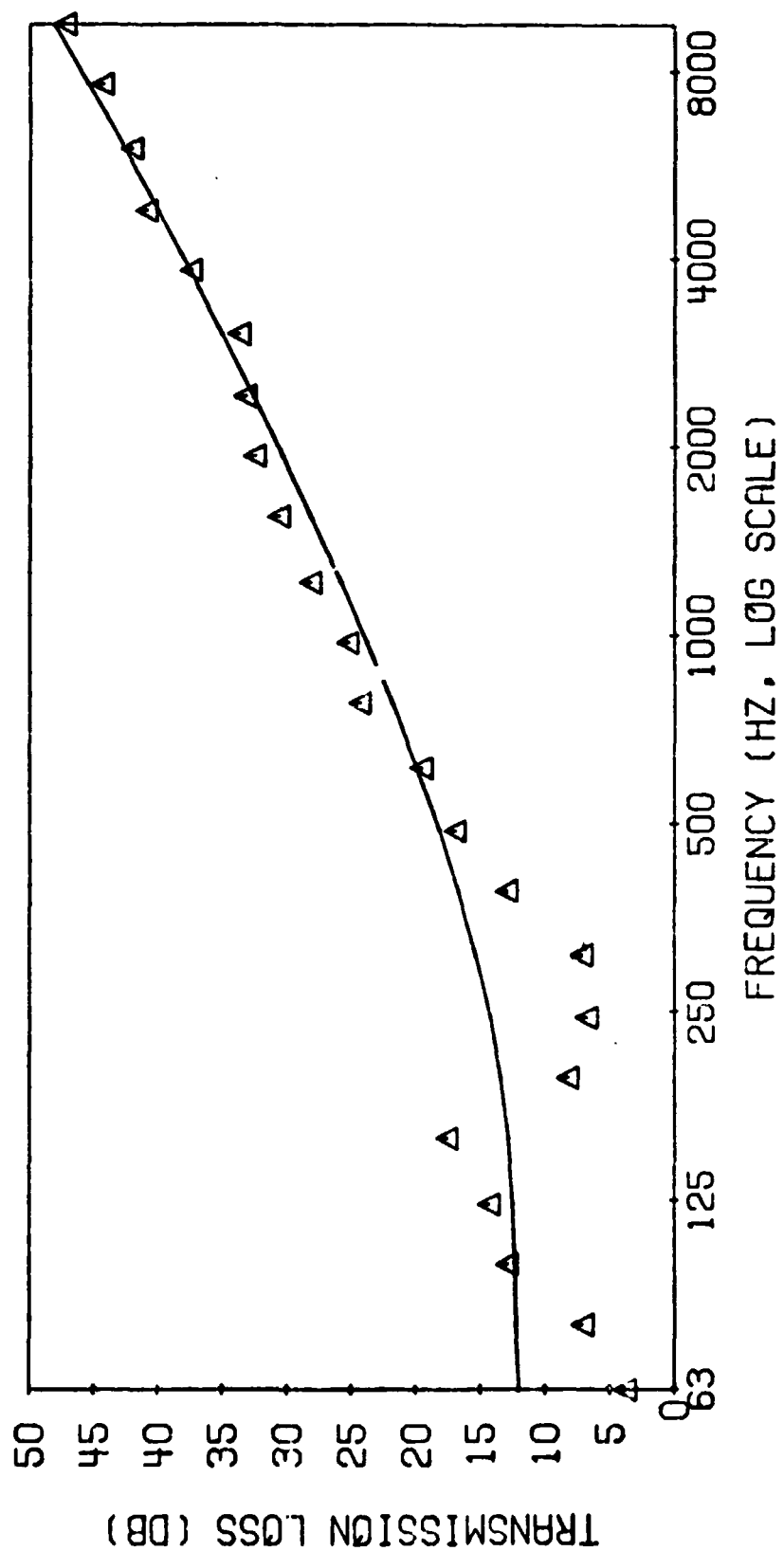of the Plexiglass Window on the Piper Cherokee Aircraft Fuselage.

Fig. 2.   Comparison Between Theoretical Prediction ———— of Transmission Loss
and the Measured Results (at 1/3 Octave Center Frequencies, Marked as Δ)
of the Combination of a Plexiglass Window and a Window Shade on the
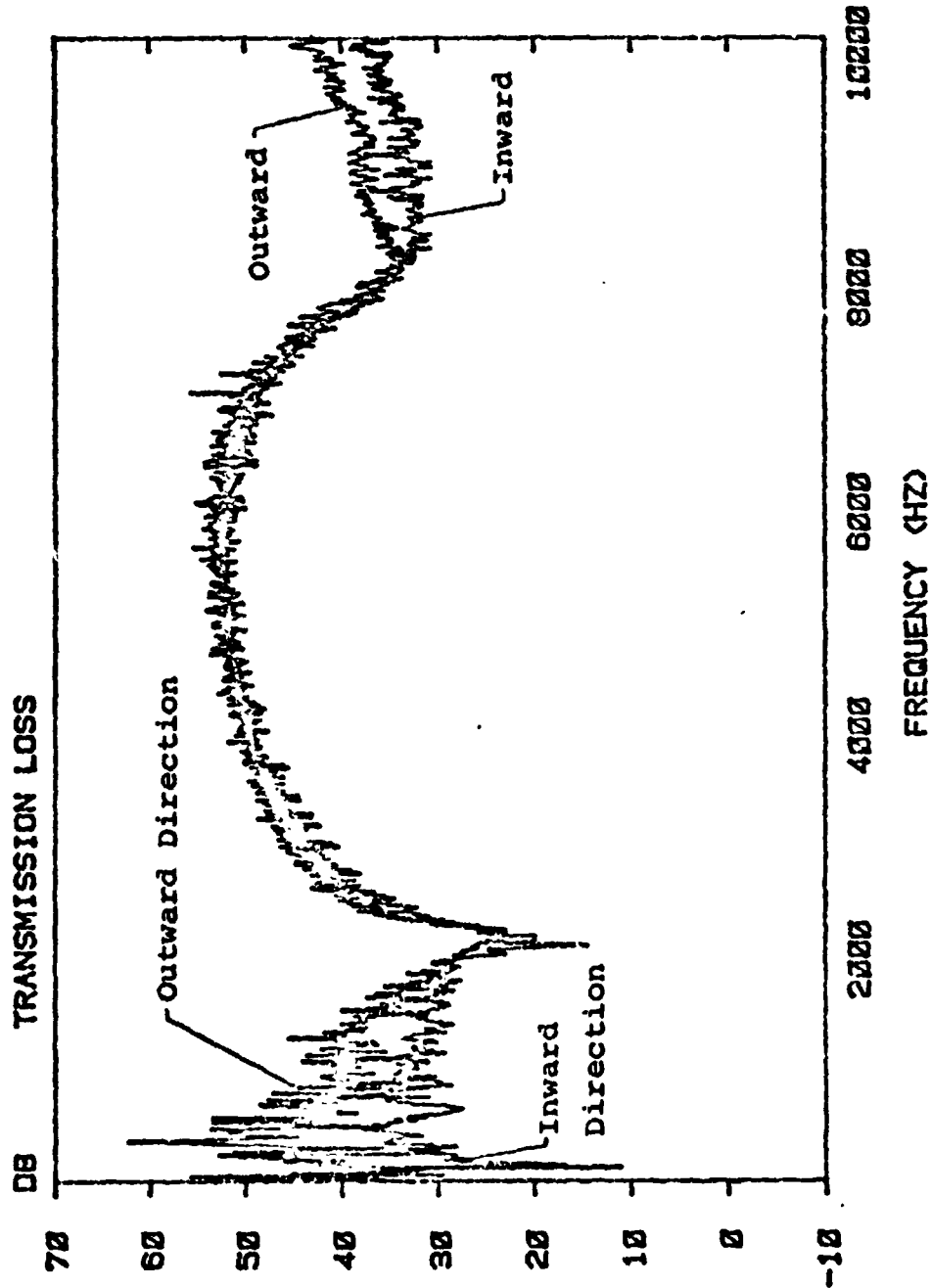Piper Cherokee Aircraft Fuselage.

Fig. 3.   The Transmission Loss of the Cylindrical Shell Measured
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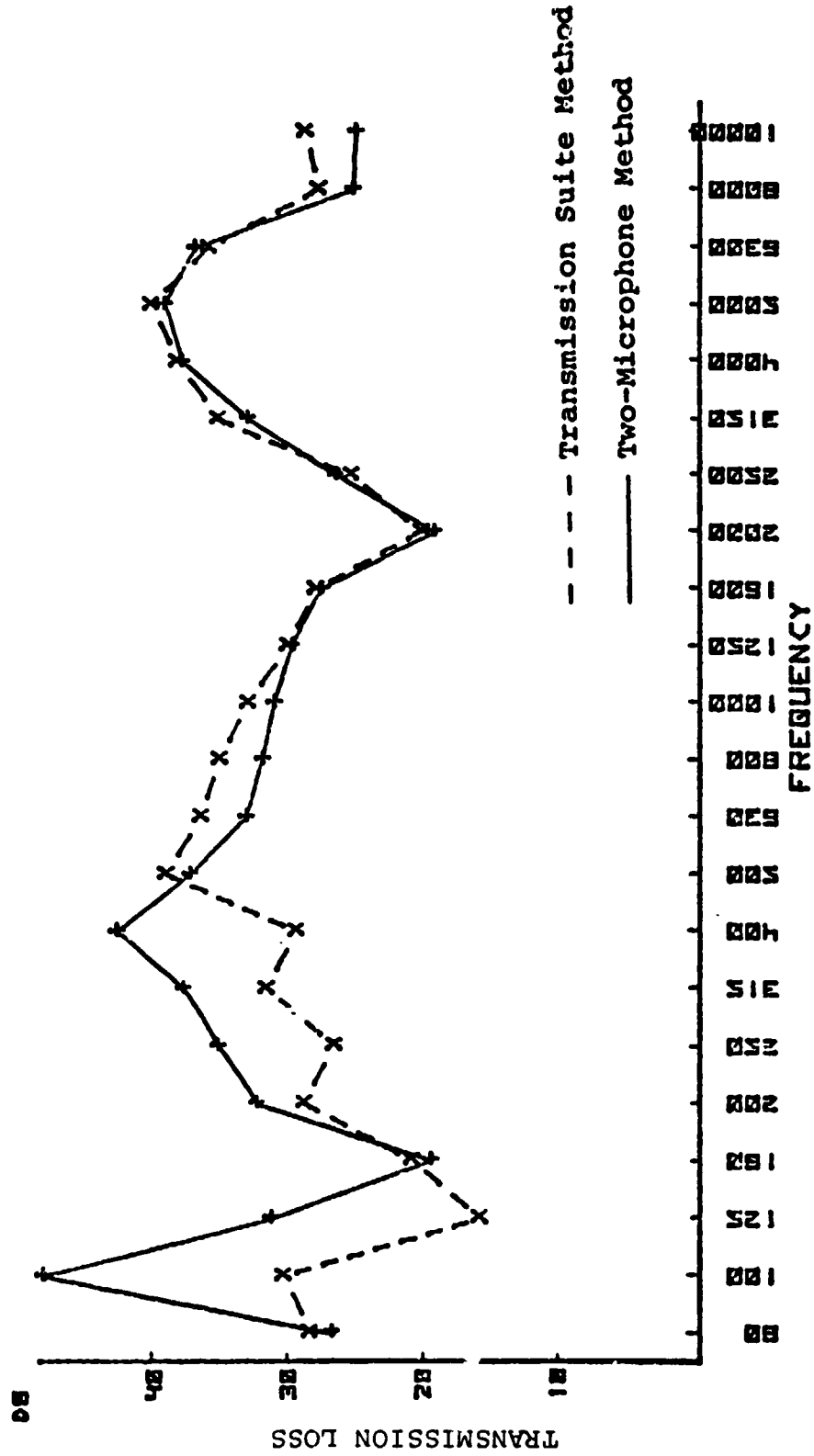
Fig. 4. Transmission Losses of the Cylindrical Shell Me sured with
         Transmission Suite Method (- - - -) and Two Microphone Intensity
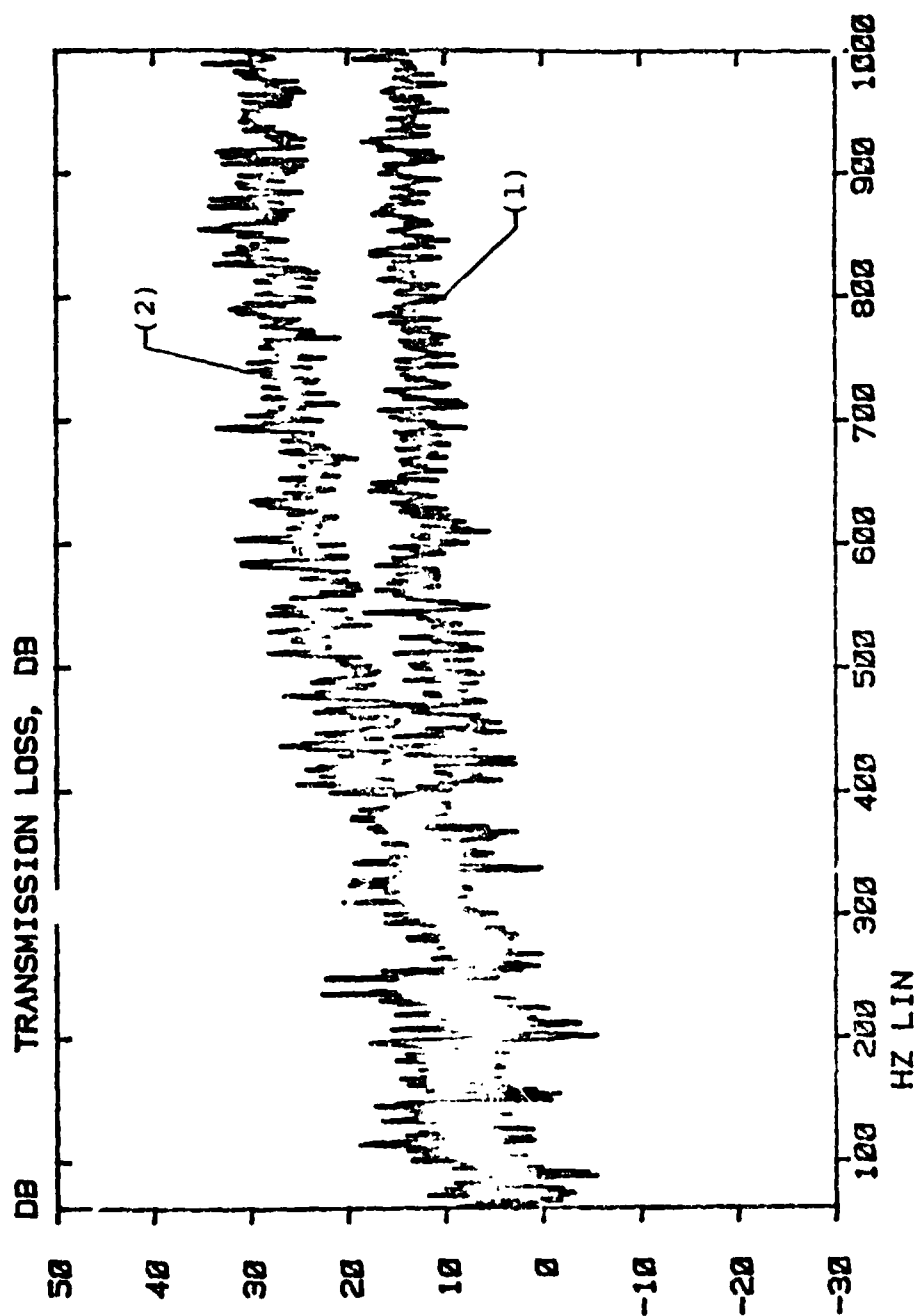   Method (————).

Fig. 5.   Comparison of (2) Transmission Loss Between the Aluminum
Panel (with Trim and Fiberglass Spacer) and (1) the
Transmission Loss of the Plexiglass Window in the Low
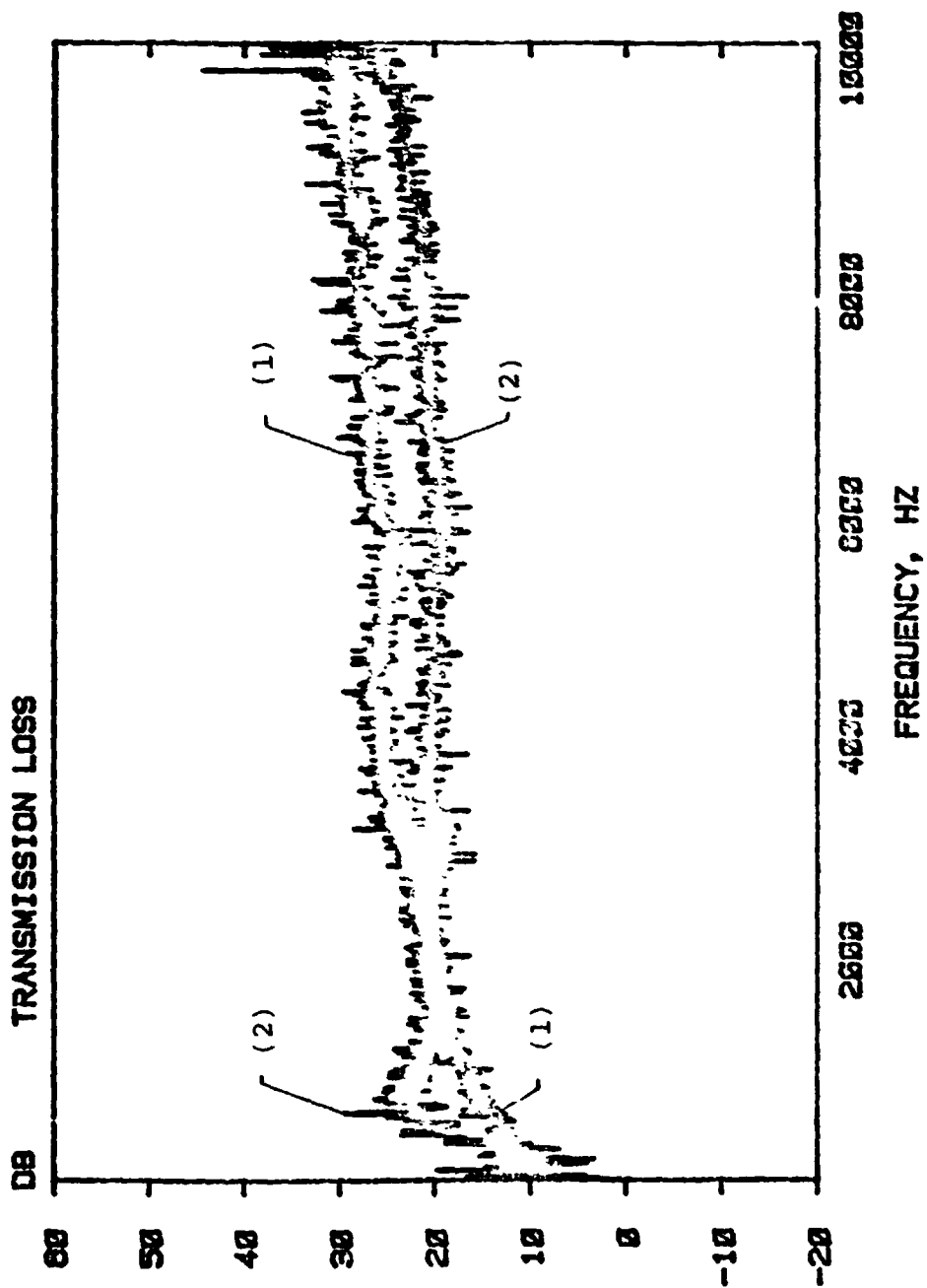Frequency Range.

Fig. 6. Transmission Loss of the Entire Door (1) Compared with
that of the Door Slit (2) of the Aircraft Fuselage.

PART II

1. INTRODUCTION

This part of the report is concerned with the continuing progress made in the transmission studies of the homogeneous, composite and stiffened panels as well as the sound transmission into a small enclosure through a stiffened panel covering one side of the enclosure.

During the past six months, April to October 1981, mostly experimental work was carried out. After writing up the Annual Report [1], this period began with sound transmission studies on the stiffened panel exposed to narrow band excitation. Then software was developed and used to measure the radiation efficiency of a homogeneous panel. This work was followed by a set of measurements on the sound transmission through a stiffened panel [1] into a small enclosure, for the case of broad band excitation. Lastly, a package of software to measure the internal loss factor by use of the acoustic intensity technique was also written. These efforts are now briefly described.

2. SOUND TRANSMISSION OF A STIFFENED PANEL SUBJECT TO NARROW BAND EXCITATION

In the previous report [1], a new technique for measuring the transmission loss of panel structures was presented. In this technique, panel structures are mounted in a small window on one

of the walls of a large reverberation room, with the exterior
side of the panel facing the interior space of the room. The
interior sound field was, for frequencies above about 200 Hz,
considered to be diffuse. This type of excitation field was
chosen for three reasons. Firstly, this would enable an adequate
comparison to be made between results obtained from the new tech-
nique and those from the conventional transmission suite method.
In the conventional transmission suite method, reverberant fields
are assumed to be created inside both the source and receiving
rooms. Secondly, using this type of excitation, both the space
and panel structure would possess diffuse fields. This situation
is desired for the comparison with the SEA prediction. Thirdly,
a diffuse reverberant sound field is the only sound field which
it is relatively easy to create in practice in the laboratory
with confidence. However, this type of excitation is quite dif-
ferent from the actual sound field incident on a real fuselage.
Such a real sound field is characterized by discrete frequency
peaks of very high sound pressure level, with a spacing in the
frequency domain controlled by the blade passage frequency and
multiples [2]. In order to investigate the performance of the
new technique in the presence of a realistic excitation, the
transmission loss of one of the panels, the stiffened panel, was
measured for a narrow band excitation. In this case, the sound
field was produced by passing a narrow band signal from a BK 1022
beat frequency oscillator via an amplifier to a loudspeaker posi-
tioned in a corner inside the reverberation room. The frequency
was monitored with a separate frequency counter. The incident

intensity on the panel, was obtained from the auto-spectrum of the pressure signal of a microphone mounted on a rotating boom placed in the center of the room. The boom was rotated in a non-horizontal plane. The transmitted intensity was measured by sweeping the intensity probe with an approximate speed of 4 mm/sec very close to a fine mesh of sewing thread, forming a plane outside the channel beams [1]. The intensity probe consisted of two BK 4165 microphones in a side by side configuration. The result, shown in Figure 1, consists of super-imposed SEA predictions of and measurements obtained for broad band and pure tone excitation. It can be seen that the measured values for both types of excitation are in close agreement with the predicted transmission throughout most of the frequency region. All measured values, except the lower values at 80 and 100 Hz, were obtained with a microphone spacing of 13 mm. In order to achieve better agreement at 80 and 100 Hz, the microphone spacing was increased to 74 mm.

It might be of interest to note that theoretical studies of the error introduced by the finite difference approximation in the cross spectral formulation of the acoustic intensity for the case of monopole, dipole and quadrupole fields have been made by other researchers at the Herrick Laboratories [3,4]. Of these fields, the largest error in the low frequency region seems to occur for the quadrupole field. In the worst case, the following guidelines for the probe geometry and distance to surface and for an accuracy within 1.5 dB were proposed:

$$0.1 < k_{\Delta r} < 1.3 \quad , \quad 0 < \Delta r/r \leq 0.5 \quad ,$$

where k is the wave number, Δr is the microphone spacing and r is the distance between the surface and the geometrical center of the probe. With a spacing of 74 mm, the lower frequency limit is close to 75 Hz. Most of the scanning was done at $\Delta r/r \approx 0.7$. Although the radiated field is presumably more complicated than that of a quadrupole, it is interesting that, at least in this measurement, the suggested guidelines proved quite useful.

In summary, it seems possible to measure the transmission loss of panel structures by use of the acoustic intensity technique even for "pure tone excitation." The performance in the lower frequency region for this type of excitation is improved if the microphone spacing is increased. Until other guidelines have been proposed and carefully examined, it is suggested that the aforementioned guidelines are used. Certainly, with a higher microphone sensitivity, better results can be anticipated, so the application of these guidelines should be combined with the use of sensitive microphones such as those used in the present research work.

3. RADIATION EFFICIENCY OF A CLAMPED HOMOGENOUS ALUMINUM PANEL

In the SEA modeling of the panel structures (homogeneous, composite and stiffened panels) presented in the previous Annual Report for NASA, Maidanik's expression for the radiation resistance was used. In order to check the validity of the predicted values of the radiation efficiency using this expression for the

case of airborne excitation, the radiation efficiency of the homogeneous aluminum panel was studied. A computation of the radiation efficiency requires a knowledge of the space-averaged and time-averaged radiated power and surface velocity.

The radiated power was measured with the acoustic intensity technique. An interactive keyboard program for the HP 5451C FFT system was developed to measure the surface velocity. Once the radiated power and surface velocity had been measured in narrow bands, they were one-third octave band filtered. A fair amount of time was spent to develop a sophisticated Fortran program for this filtering. By use of this routine, only the energy area falling within standardized filter skirts down to 50 dB from the level of the center frequency was represented by the computed one-third octave band values. Possible negative values of the radiated power (before taking the log magnitude) were excluded in the summation. Another Fortran routine was written to evaluate the radiation efficiency in both narrow bands and one-third octave bands. The results are shown in Figures 2 and 3.

It can be seen in Figure 2 that the radiation efficiency increases with frequency up to about 4000 Hz after which it drops. The measured one-third octave band filtered radiation efficiency together with the corresponding prediction using Maidanik's theory (where 3 dB has been added to the ratio in the bands below 4 kHz to allow for clamped conditions) is shown in Figure 3. Clearly, the measured values are underestimated by the theory. A better agreement between this theory and measured

values for the case of mechanical excitation was obtained by Crocker [5]. The difference in the measured radiation efficiency for airborne and mechanical excitation has been experimentally verified by Macadam [6]. However, this difference was not adequately explained. A possible explanation is as follows.

In the case of mechanical (point) excitation almost all modes are equally excited. Since in Maidanik's theory all modes are assumed to be excited equally, a fair agreement between theory and experiment can be anticipated for this case of mechanical point excitation. On the other hand, when a panel is excited by a diffuse sound field, only modes in the panel which are well coupled with the incident field are excited. These modes are in turn efficient sound radiators and thus radiate well into space. Thus considering two panels excited by a diffuse field and by point excitation, the panel excited by the diffuse field should radiate more efficiently than the point excited panel.

4. FURTHER WORK

Some time was spent to collect more data on the sound transmission into a small enclosure. This has not been processed yet. A method of utilizing the acoustic intensity technique to measure the internal loss factor is in an initial stage of development. Most of the software (including several keyboard programs and Fortran routines on the HP 5451C FFT) has been developed, and is to be tested, when time permits. A quite

extensive literature on transmission loss theories, SEA modeling
and the acoustic intensity technique was also written up at the
end of the period from April to October 1981.

5. REFERENCES

[1]   Forssen, B., Wang, Y.S., Raju, P.K., and Crocker, M.J., "A
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      Transmission of Sound Through the Walls of Light Aircraft,"
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[3]   Thompson, J.K., "Evaluation of the Conventional and Acous-
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[4]   Thompson, J.K., and Tree, D.R., "Finite Difference Approxi-
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      Statistical Energy Analysis," J. Sound and Vib., (9), pp.
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[6]   Macadam, J. A., "The Measurement of Sound Radiation from
      Room Surfaces in Lightweight Buildings," Applied Acoustics,
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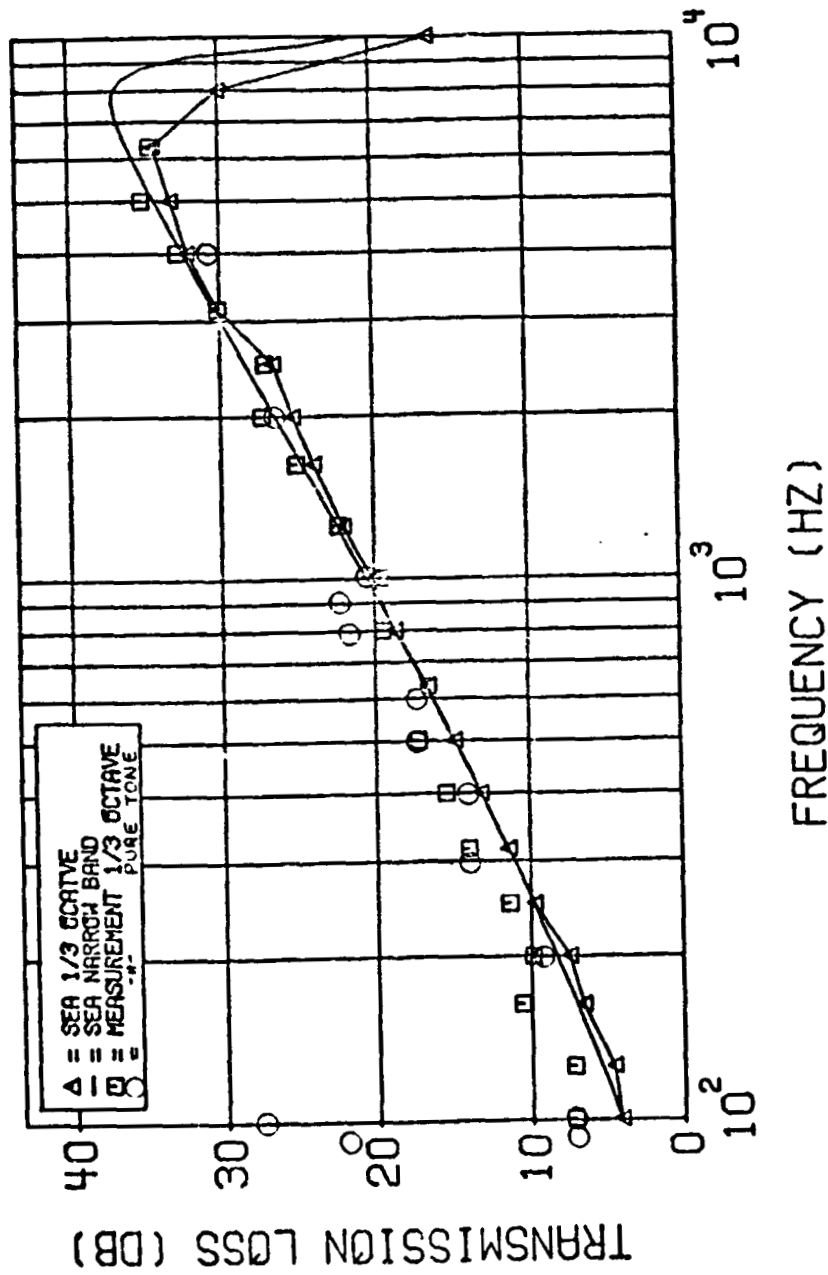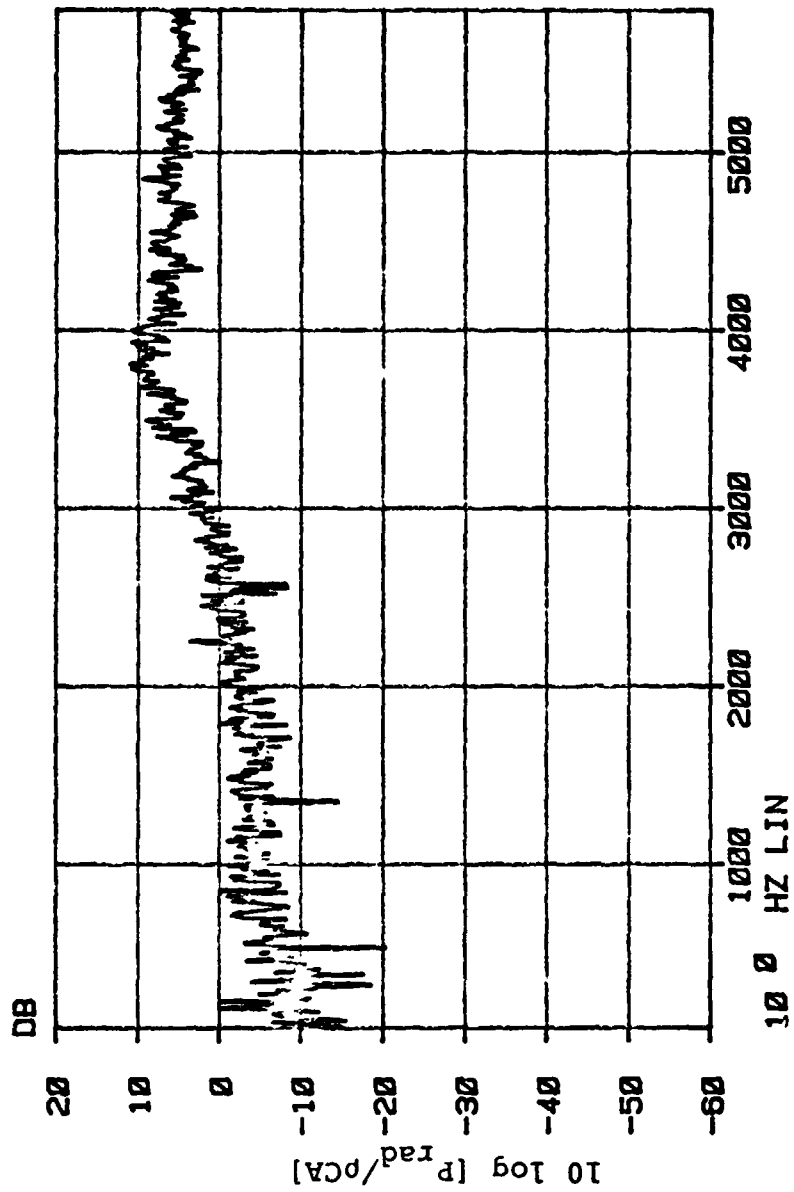Fig. 1. Transmission Loss of the Stiffened Panel.

Fig. 2. Radiation Efficiency, Presented in Narrow Frequency
Bands, for a Clamped Homogeneous Aluminum Panel
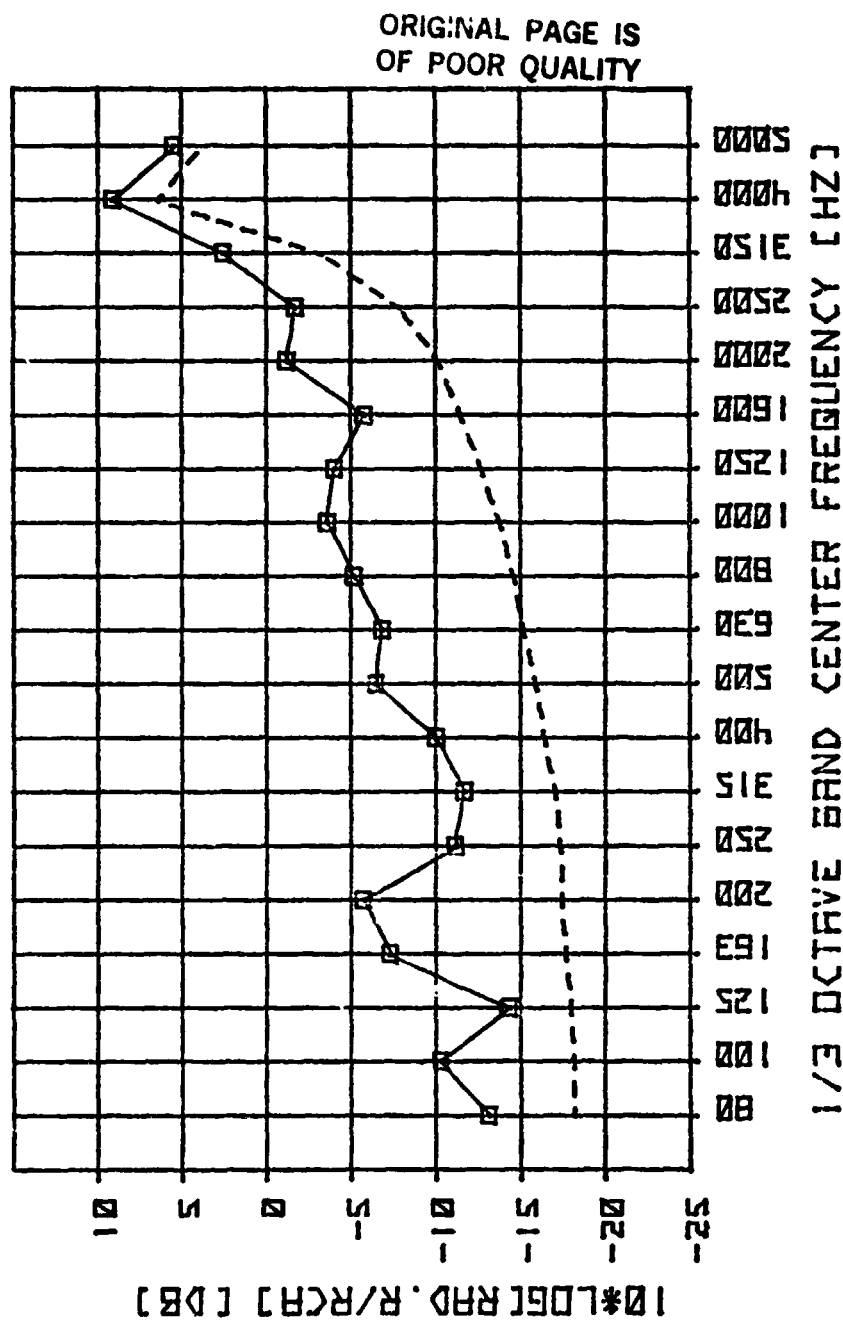(3.18 mm thick) with Airborne Excitation.

Fig. 3.   Radiation Efficiency, Presented in 1/3 Octave Bands,
          for a Clamped Homogeneous Aluminum Panel (3.18 mm thick)
          with Airborne Excitation. ─⊟─ Experiment, ──── Maidanik